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Flood Hazard Assessment in Eastern Slovakia

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ABSTRACT

The main objective of this paper is to assess flood hazard in river basins in the eastern Slovakia for the purposes of flood risk management. Multicriteria analysis (MCA) specifically ranking method (RM), analytic hierarchy process (AHP) and geographical information system (GIS) are used for evaluation flood hazard areas. In this paper we describe and test approaches which combine MCA and GIS. GIS with their ability to handle spatial data are an appropriate tool for processing spatial data on flood risk.

Keywords— Flood hazard, analytic hierarchy process, ranking method

1. INTRODUCTION

A new comprehensive approach on flood risk assessment and management on a European level has been triggered especially, after the large-scale flooding of 2002 in central Europe, with an estimated damage of 16.5 billion US$ (2002: 1 US$ = 1€). The European Commission issued a Communication about flood risk management in 2004. This initiative was followed by the adoption by the European parliament and the council of Directive 2007/60/EC on the Assessment and Management of Flood Risks on 23 October 2007. The purpose of Directive 2007/60/EC is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment,

cultural heritage and economic activity associated with floods in the Community.

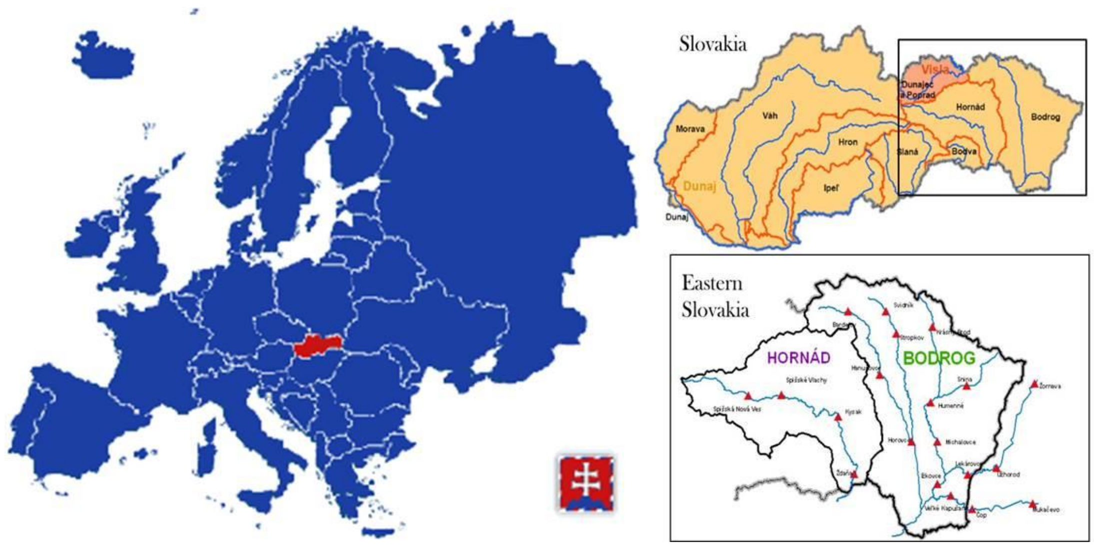

Figure 1 Study area - Hornád and Bodrog river catchments

Extreme flood events in the recent years had huge economic, social and environmental impacts and caused also losses in human life [1]. Against this already serious background, enhanced climate variability and climate change are expected to increase the frequency and intensity of floods [2].

According to 2007/60/EC EU Member States completed the preliminary flood risk assessment by 22 December 2011. Based on available or readily derivable information, such as records and studies on long term developments, in particular impacts of climate change on the occurrence of floods, a preliminary flood risk assessment were undertaken to provide an assessment of potential risks. The preliminary flood risk assessment was used to identify areas which need to be considered in more detail through mapping and potentially the preparation of flood risk management plans. In order to assess flood risk it is necessary to identify both the probability and consequences of flooding [3].

Flood hazard maps and flood risk maps EU Member States prepared by 22 December 2013. Flood risk maps have showed the potential adverse consequences associated with flood scenarios. The Exchange Circle on Flood Mapping (EXCIMAP) made an inventory of flood mapping practices in Europe. This inventory has resulted in a 'Handbook on Good Practices for flood mapping in Europe' and an 'Atlas of Flood maps containing examples from 19 European countries, Japan and USA'.

On the basis of the maps Member States shall establish flood risk management plans by 22 December 2015. Flood risk management plans shall take into account relevant aspects such as costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Directive 2000/60/EC, soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure. The purpose of the flood risk management plans is to identify means of reducing the impacts of flooding.

The main aim of this paper is to present approaches to ways of flood hazard assessment. To evaluate the flood hazard areas two methods are presented in this paper – analytic hierarchy process and ranking method. Geographic approach to flood hazard assessment provides a descriptive presentation of the obtained results.

2. STUDY AREA

The most endangered areas by floods in Slovakia are its eastern parts, particularly the Bodrog and Hornád river basins (Fig. 1). The morphological type of the terrain in Hornád river valley is dominated by rolling hills, highlands and lower highlands. The southern sub-basin is part of a plane and Slovak Kras and is formed by moderately higher highlands. Geological structure of the territory determines the hydro-geological conditions of the basin. Sub-basin of the Hornád valley can be assigned to areas with a strong predominance of impervious, respectively poorly permeable rocks with moderate to low permeability. Well-drained rocks with high permeability are only in some areas (Spiš and Gemer areas and in Slovak Kras near Košice) [3]. Territory of Bodrog River (Fig. 1) – Cirocha, Laborec, Latorica, Ondava, Topľa and Uh river basins – is located in two orographic subassemblies, which are the Carpathians and Pannonian Basin [3].

The morphological type of the relief is predominantly plane in the southern part, hilly in the northern part. Bodrog river valley has varied climatic conditions. Precipitations are highly differentiated. The highest annual totals are mainly at east border mountains (Vihorlat) where rainfall totals is about of 1000 mm. Decrease of total precipitation is quite intense direct to the south - annual totals fall to below 800 mm. Lowland part of the territory (Michalovce - Lastomír and Medzibodrožie) belong to among the driest in the eastern region (550 mm rainfall per year) [3].

3. MATERIAL AND METHODS

The multicriteria analysis ends with a more or less stable ranking of the given alternatives and hence a recommendation as to which alternative should be preferred [4]. Regarding our problem of flood hazard assessment, the result will be a ranking or categorisation of areas with regard to their hazard level. Hence a recommendation where mitigation action is most required. The first step in assessing the hazard structure is to determine the factors affecting floods on the basis of an analysis of existing studies and knowledge. In this study were considered the following factors:

- Soil type
- Rainfall

- Land use
- Size of watershed
- Slope

The inverse ranking was applied to dividing these factors into classes the least important = 1, next least important = 2, etc. (Tab. I).

TABLE I THE SIGNIFICANCE OF THE IMPACT OF FLOODING CAUSATIVE FACTORS

Classes	Causative factors				
	Rainfall [mm]	***Slope [%]***	***Content of clay particles [%] (Soil type)***	***Land use***	***Size of watershed [km²]***
1	0 - 1.8	0 - 15	0 - 10	forest	0 - 100
2	1.8 - 2.0	15 - 30	10 - 30	-	100 - 500
3	2.0 - 2.2	30 - 45	30 - 45	agricultural	500 - 1000
4	2.2 - more	45 - 80	45 - 60	-	1000 - more
5	-	80 - more	60 - more	urbanized	-

TABLE II MATRIX OF FLOOD CAUSATIVE FACTOR

River station	Causative factor	Classes				
		1	***2***	***3***	***4***	***5***
Streda nad Bodrogom	Rainfall	1	0	0	0	0
	Soil type	0	0	3	0	0
	Land use	0	2	0	0	0
	Slope	1	0	0	0	0
	Size of watershed	0	2	0	0	0

A. *Analytic hierarchy process*

The first method for determining the flood hazard areas is analytic hierarchy process. The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education. Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions [5].

The fifteen river stations in the Latorica, Laborec, Cirocha, Topľa, Ondava, Bodrog, Hornád and Torysa streams were assessed. For each river station was established matrix 5 x 5 – factors x class (1 - 5). This matrix was completed with values from 1 to 5, depending to what class the factor in river station is located in the following way: e.g. when river station is located in an area where rainfall belong to class one, so to the line "rainfall" and column "1" was written number 1, other values in this line are zero. In this way the whole matrix was completed for all factors. Example of a completed matrix for river station Streda nad Bodrogom is shown in Tab. II.

To determine the weight of each river station was used AHP method, which was programmed in Microsoft Excel. The matrix was developed for all 15 river stations.

B. *Ranking method*

The second method for determining the flood hazard areas is ranking method. In ranking method (RM), every criterion under consideration is ranked in the order of the decision maker's preference. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance for causing flooding [6]. The straight ranking was applied to these factors, 1st is the most important factor and 5st is the least important factor:

1st – Rainfall
2nd – Slope
3nd – Soil type
4rd – Land use
5th – Size of watershed

The purpose of the criterion weighting is to express the importance of each criterion relative to other criteria. The more important criterion had the greater weight in the overall evaluation [6]. Using rank sum method the criterion weights were calculated as [7]:

$$W = n - r_j + 1 \quad (1)$$

where: n - is the number of criteria under consideration (k = 1, 2… n), r_j - is the rank position of the criterion.

Each criterion was weighted ($n - r_j + 1$) and then normalized by the sum of weights, that is $\Sigma(n - r_k + 1)$. The normalized weight W_j of criterion j is calculated by [7] (2):

$$W_j = n - r_j + 1 / \sum (n - r_k + 1) \quad (2)$$

Table III shows weight assessment by rank sum method.

TABLE III WEIGHT ASSESSMENT BY RANK SUM METHOD

Criterion	Straight Rank	Weight (W)	Normalized Weight (W_j)	Weight in %
Rainfall	1	5	0.333	33.3
Slope	2	4	0.267	26.7
Soil type	3	3	0.200	20.0
Land use	4	2	0.134	13.4
Size of watershed	5	1	0.066	6.6
SUM		10	1.00	100

Resulting hazard was calculated using the following formula (3):

$$H = \sum (C_1 W_{j1} + C_2 W_{j2} + C_3 W_{j3} + C_4 W_{j4} + C_5 W_{j5}) \quad (3)$$

where:
C_1, C_2, C_3, C_4, C_5 – criterion,
W_{j1}, W_{j2}, W_{j3}, W_{j4}, W_{j5} – normalized weight for each criterion.

4. RESULTS

The flood hazard areas in the study area were evaluated in four classes (Tab. IV). Since the methods take into account some example conditions of the region, the results can be as realistic only for this condition. When the characteristics would change, the results will show the different conditions. The resulting scale (Tab. IV) was established on the basis of professional judgment.

TABLE IV HAZARD ACCEPTABILITY AND ITS SIGNIFICANCE

Hazard rate	Hazard acceptability	Significance of flood hazard in watershed	Scale of hazard	
			AHP	RM
1	acceptable	Hazard in watersheds are acceptable – current practice	1 – 10	1 - 1,73
2	moderate	Hazard in watersheds are moderate – condition of continual monitoring	11 – 20	1,73 - 2,13
3	undesirable	Hazard in watersheds are undesirable – flood protection	21 – 30	2,13 – 2,46
4	unacceptable	Hazard in watersheds are unacceptable – immediate flood protection measures	31 and more	2,46 and more

TABLE V HAZARD FOR RIVER STATIONS

River station	Weight/Hazard
Krásny Brod	0.102286
Stropkov	0.080597
Michalovce	0.07222
Spišská Nová Ves	0.065754
Snina	0.055459
Hanušovce	0.055459
Svidník	0.055459
Humenné	0.051357
Spišské Vlachy	0.049978
Horovce	0.049406
Ždaňa	0.049406
Bardejov	0.047895
Ižkovce	0.029255
Veľké Kapušany	0.029255
Kysak	0.027339
Streda nad Bodrogom	0.018523

Analytic hierarchy process

The resulting weights for all river stations are shown in Tab. V. River stations are ranked by the value of weights from the largest to the smallest. The obtained results of flood hazard assessment presented in the program ArcGIS 9.3 are shown in Fig. 2. The flood hazard assessment results showed that Bodrog and Hornad watershed are mainly in moderate and undesirable flood hazard. Areas with unacceptable and acceptable hazard have been identified in only a relatively small area. Area with an undesirable flood hazard covers the northern part of eastern Slovakia and represents 65.51% of the study area. Unacceptable hazard was found in the surroundings of Krásny Brod and Stropkov and represents 3.43 % of the study area. Southeastern part of Slovakia belongs to the moderate hazard areas and the percentage of valuing land is 30.42 %. Acceptable hazard is a very small part of the territory and belongs to 0.64 %. The area of acceptable hazard has been detected around Streda nad Bodrogom – south of Slovakia.

Ranking method

A composite map (Fig. 3) shows the flood hazard areas that were created by using ranking method with software ArcGIS 9.3. In this application, the range numbers are designated as acceptable, moderate, undesirable, unacceptable on the output map depicting the level of flood hazard of the study area.

Percentage of each zone to flood hazard was calculated as 18.43 % (acceptable), 40.25 % (moderate), 28.99 % (undesirable) and 12.33 % (unacceptable) respectively the first shows area less susceptible to flood and as it progresses the vulnerability structure increases (Fig. 3).

The results are mostly coincident with the results from preliminary flood risk assessment which has to be done in the Slovak Republic in 2011. The results of mentioned assessment are presented in Fig. 4. The geographical areas with existing potentially significant flood risk are marked in red color. The geographical areas with probable potentially significant flood risk are marked in yellow color.

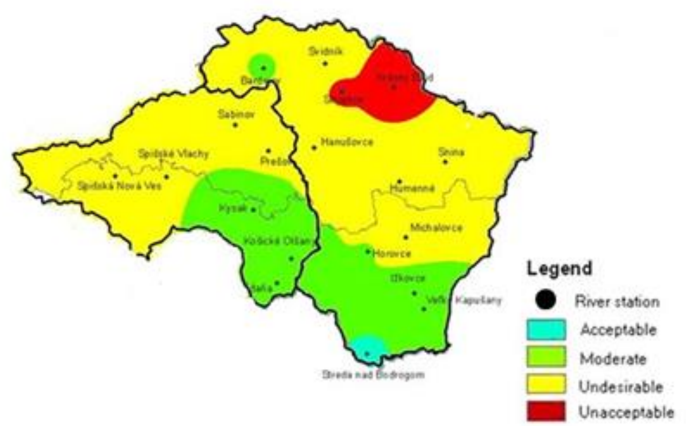

Figure 2 Map of flood hazard in study area based on AHP

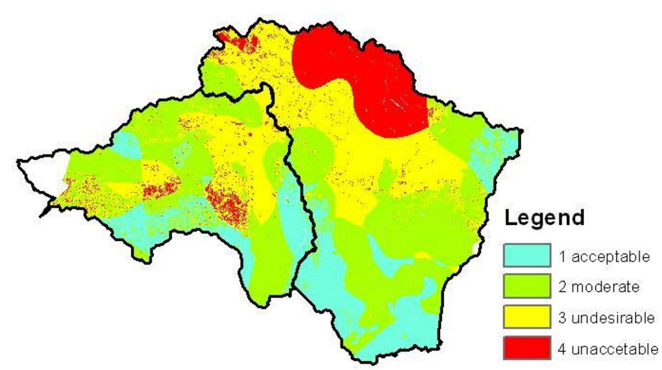

Figure 3 Map of flood hazard in study area based on RM

Geographic approach to flood risk assessment provides a descriptive presentation of the results obtained [8]. Created thematic maps show the suitability of using ArcGIS software wherever it is necessary to make quick and effective decisions in emergency relief efforts for flood protection needs. People must learn to live with floods in the future. The value of the property threatening flooding is increasing. Therefore, attention must focus on the whole society to prevent and protect itself from big water to reduce or damage minimized. Floods can anywhere and anytime have disastrous consequences, so it is desperately important to place emphasis on early warning and adequate protection against flooding.

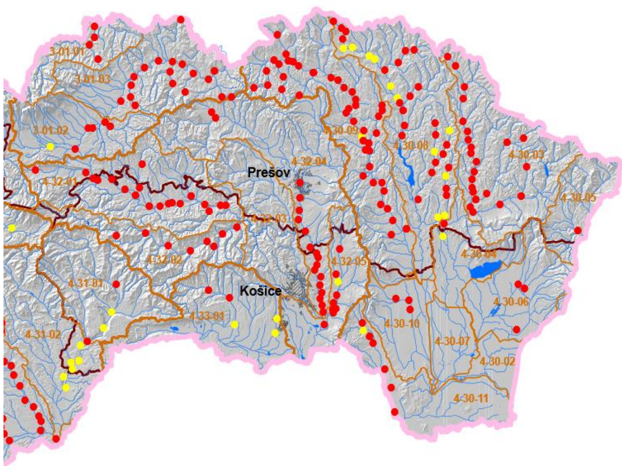

Figure 4 Geographical areas with potentially significant flood risk

The appropriate flood risk mitigation investment, and the redirection of resources into flood disaster prevention, offers significant economic benefits, as well as reduction in loss of life and property, improvements in welfare and social stability.

5. CONCLUSION

There are three components in assessing risk of disaster. The first is the hazard, the probability of the occurrence of potentially damaging phenomena within a specified time and given area. The second is the element or elements at risk. These mainly are regarded to be population, property, and economic activities in a given area. The third is vulnerability. The main aim of this paper was evaluate the flood hazard areas using multicriterial analysis methods – analytic hierarchy process and ranking method. In the paper were evaluated the causes of extreme hydrological events in catchments (Hornád and Bodrog) – flood hazard areas in the territory of eastern Slovakia. The flood hazard areas in the study area were evaluated in four classes: acceptable, moderate, undesirable and unacceptable. The flood hazard assessment results showed that Bodrog and Hornád watershed is mainly in moderate and undesirable flood hazard. It is because only natural conditions like morphology were assessed. The following recommendations are made for upgrading this hazard map:

1. Drainage density, evaporation, percolation etc. can be included for further studies.
2. Factors such as frequency of flood, inundation depth, duration of flood, etc. should be considered for the future studies.
3. Conversation with local people and survey are very important work for making an effective flood vulnerability maps. Mentioned research is presently realized.

Determination of the areas at hazard is needed for flood management - flood warning, floodplain development control and flood mitigation measures design.

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REFERENCE

1. Korytárová, J., Šlezingr, M. and Uhmannová, H. 2007. Determination of potential damage to representatives of real estate property in areas afflicted by flooding. Journal of Hydrology and Hydromechanics, vol. 55, issue 4, p. 282–285, 2007.
2. United nations economic commission for Europe. 2009. Transboundary Flood Risk Management: Experiences from the UNECE Region. New York and Geneva.
3. Zeleňáková, M. 2010. Geographical approach to flood risk analysis. Proc. from International scientific conference: People, buildings and environment 2010. Brno: CERM, p. 442-447.
4. Meyer, V. 2007. GIS - based Multicriteria Analysis as Decision Support in Flood Risk Management. FLOODsite. Project Report. Contract No: GOCE-CT-2004-505420.
5. Omkarprasad, S. V. and Sushil, K. 2006. Analytic hierarchy process: An overview of applications. European Journal of Operational Research, vol. 169, issue 1.
6. Yalcin, G. and Akyurek, Z. 2004. Analysing flood vulnerable areas with multricriteria evaluation. http://proceedings.esri.com/library/userconf/proc04/docs/pap1097.pdf>.
7. Yahaya, S., Ahmad, N. and Abdalla, F.R. 2010. Multicriteria Analysis for Flood Vulnerable Areas in Hadejia-Jama'are River Basin, Nigeria. European Journal of Scientific Research. Vol.42, No.1, pp 71-83. 2010.
8. Gergelova, M., Kirov, B. and Blistan P. 2008. Digital modelling of floods. In: SGEM 2008. Volume 2. - Sofia : SGEM, 2008 p. 599-604.